

4 Final Report  
 Covering Period 11 May 1966 to 1 March 1967 6

3 LIGHTWEIGHT SOLAR PANEL INTERCONNECTIONS 4

Prepared for  
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 Contract NAS5-10187-29ACV

29B EOS Report 7088-Final 29 9 August 1967 10CV

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## SECTION 1

### INTRODUCTION AND SUMMARY

This final report covers the work performed under Tasks I, II, III and IV on NASA/GSFC Contract NAS5-10187, Lightweight Solar Panel Interconnections. The object of this program was to develop the basic technology required to electroform silver or copper interconnections between commercially available wraparound silicon solar cells with silver-titanium sintered contacts. It is anticipated that when developed fully, the electroforming technique could provide a highly reliable interconnection between solar cells and improve panel assembly techniques. To demonstrate the feasibility of the electroforming technique the following was accomplished.

- Basic Technology. - The required electroforming technology was established including setup of the electroforming equipment, establishing the plating parameters, developing mandrels and masking to reliably electroform silver and copper tabs on single solar cells, and performing physical and electrical tests on these cells.
- Two-Cell Interconnections. - Basic technology was established to develop interconnection between two solar cells. Development of mandrel and masking techniques for two-cell interconnections and testing of the interconnections were included under this task.
- Four-Cell Modules. - The two-cell interconnection techniques were extended to a four-cell module, including fabrication of several four-cell modules for evaluation by EOS and NASA/GSFC.



- Assembly and Development Techniques. - This included analysis and experimental verification of solar cell assembly and replacement techniques.

Basic electroforming techniques have been developed which have resulted in attachment of a silver interconnection to single 12.5-mil wrap-around or conventional solar cells, between two solar cells, and between four solar cells. These interconnections have passed N-Contact pull and thermal shock tests (see Subsections 2.1.5.2 and 2.1.5.3). The only noticeable effect the electroforming process has on the cell is an etching of the silicon monoxide surface layer. This should be eliminated when the proper combination of sealing technique and material is found for the silver cyanide electroforming bath. Attempts to electroform copper tabs on the solar cells have proved unsuccessful; in view of the successful results with silver further experiments with copper are not recommended.

The solar cells used for feasibility studies were 2 x 2 cm N/P silicon solar cells, using sintered Ti-Ag contacts. The cells were not required to meet any definite electrical specifications and were measured before and after processing (see Subsection 2.1.5.1). Each cell was subjected to a standard Scotch tape test. In order to successfully electroform, each cell was ground so that the "picture frame" on the P contact was 5 mils or less on one side. Each cell had a silicon monoxide coating.

The program was concluded with delivery to NASA/GSFC of 4 four-cell modules and 10 single-cell modules.

## SECTION 2

### TECHNICAL DISCUSSION

#### 2.1 SILVER ELECTROFORMING

A silver electroforming process line was set up as shown in Fig. 1. The electroforming process consists of these basis steps:

- Activating the sintered silver-titanium contacts of the cells
- Silver striking to obtain better adhesion to the solar cell contact
- Silver electroforming

Each of the solutions used was prepared per the manufacturer's recommendations (included as Appendix I). Electroforming of copper tabs was attempted using an existing EOS copper pyrophosphate electroforming bath shown in Fig. 2.

##### 2.1.1 ELECTROFORMING PARAMETERS

The electroforming process is affected by several variables which must be fixed for each specific application. Once these parameters are fixed they can be closely maintained to insure the quality of the deposited material is maintained. The following parameters were investigated by making several test platings:

- Bath composition
- pH
- Current density
- Plating temperature

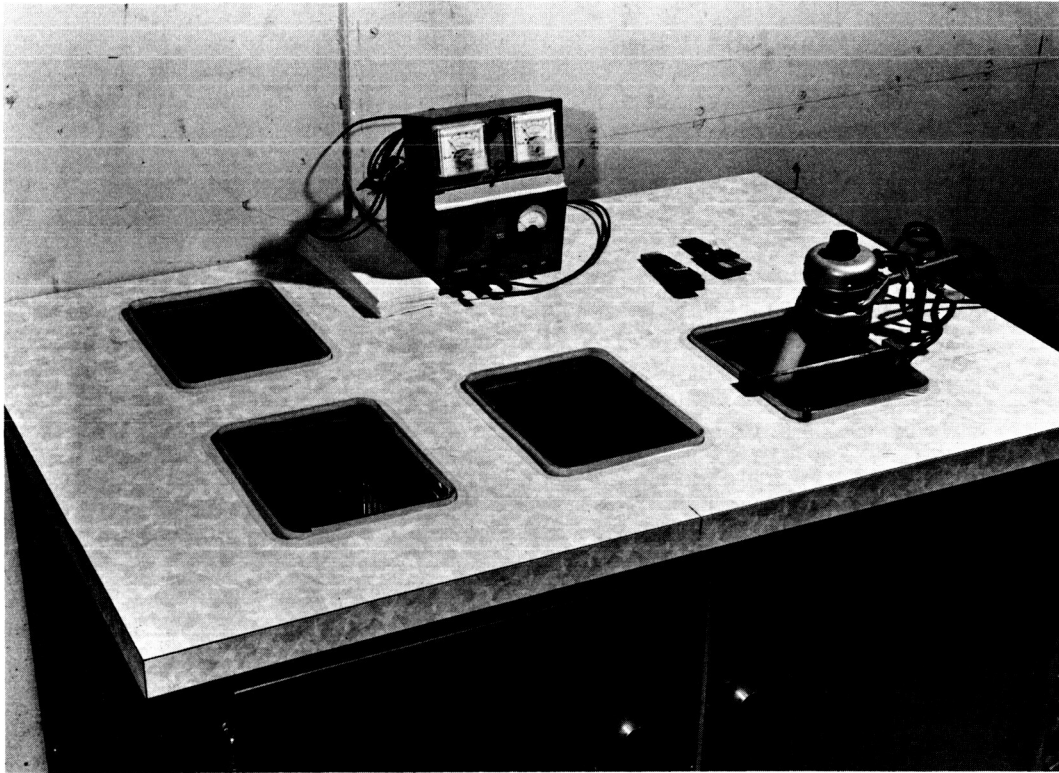


Figure 1. Silver Electroforming Setup

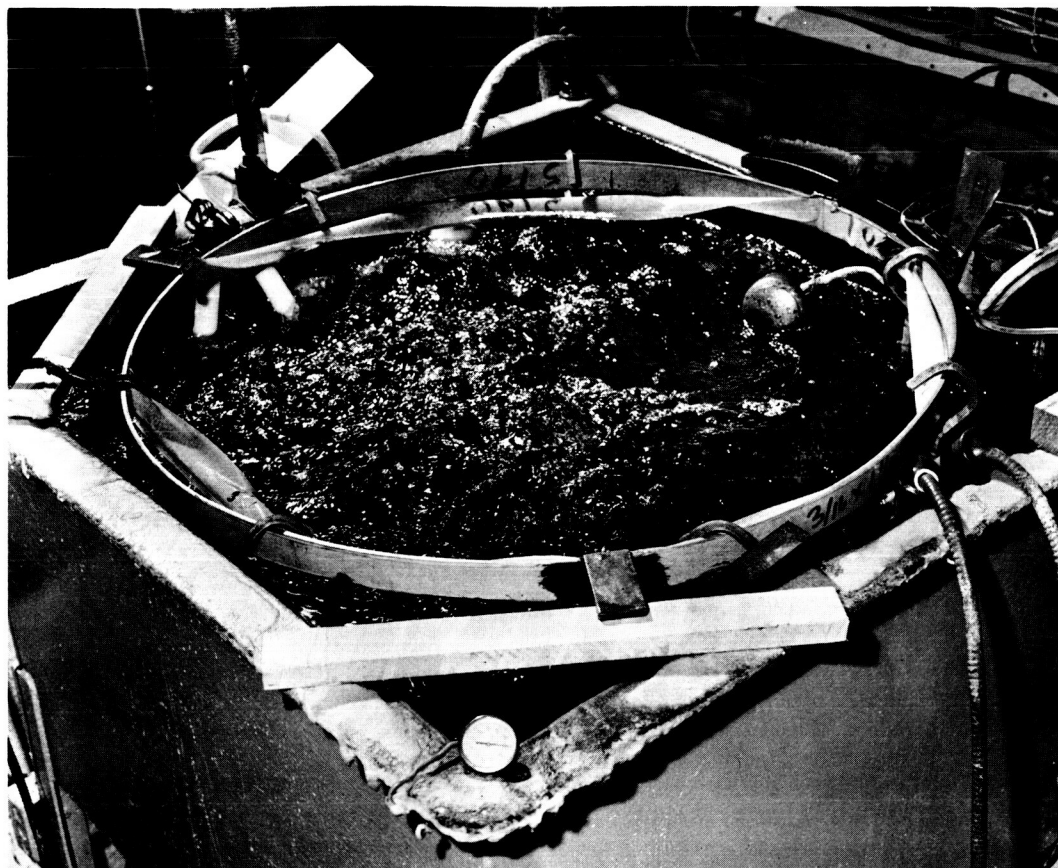


Figure 2. Copper Electroforming Bath

The final combination of parameters as established for the silver and copper electroforming baths is shown in Table I.

TABLE I  
Ag AND Cu BATH PARAMETERS

Parameter	Silver Bath	Copper Bath
Bath composition	M&T Chemicals Spec (P-Ag-SL)	M&T Chemicals Spec (P-Cu-10X)
pH	11 to 12.5	8.25 to 8.5
Current density	10 A/ft <sup>2</sup>	8-12 A/ft <sup>2</sup>
Temperature	100-110°F	120-135°F

#### 2.1.2 PHYSICAL PROPERTIES

The physical properties of the electroformed silver and copper were established by electroforming 4-mil panels from which tensile specimens were cut. Five tensile specimens were prepared from each panel as shown in Fig. 3. The average tensile test results are tabulated in Table II.

TABLE II  
TENSILE TEST RESULTS FOR Ag AND Cu

Property	Silver	Copper
Ultimate tensile strength, KSi	Sult 30,520 psi	Sult 55,280 psi
Yield strength (0.2% offset) KSi	Syd 24,940 psi	Syd 36,740 psi
Elastic modulus 10 <sup>6</sup> psi	e 17.0%	e 14.2%
Ultimate elongation (1-inch gage length)	E 8.3 x 10 <sup>6</sup> psi	E 12.0 x 10 <sup>6</sup> psi

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**Figure 3. Tensile Test Specimen, Thin Foil Materials**

The minimum required tensile strength was established using a minimum tab thickness of 3 mils and a width of 0.050 inch. Based on maximum load requirement of 800 grams and a safety factor of 1.5, the minimum required ultimate tensile strength is 18,000 psi. Both the copper and silver met these minimum requirements.

#### 2.1.3 MANDRELS AND MASKING

The basic requirement of the electroforming process was to electroform an adherent tab to the solar cell. The major problem is obtaining a continuous electroformed layer across the joint between the cell and the mandrel which defines the shape of the tab. Preliminary experiments attempting to electroform copper tabs using RTV and phenolic mandrels were not successful. The copper would not plate across the gap between the cell and the mandrel.

Additional studies were made to establish what gap width could be successfully bridged by electroforming. The results indicated that silver plates across gaps somewhat better than copper. A 10-mil gap was bridged with the electroformed silver.

In order to minimize the gap between the solar cell and the mandrel, a combination stainless steel-phenolic mandrel was fabricated. A cross section of the mandrel is shown in Fig. 4. The stainless steel tab mandrel is placed against the edge of the solar cell, giving a gap of approximately 0.5 mil. The cover and RTV seal limit the plating to the required surfaces. This mandrel concept successfully electroformed several silver tabs on single wraparound cells.

#### 2.1.4 ELECTROFORMED TABS

Attempts were made to electroform silver and copper tabs using the mandrel and masking cover described in Fig. 4. The silver

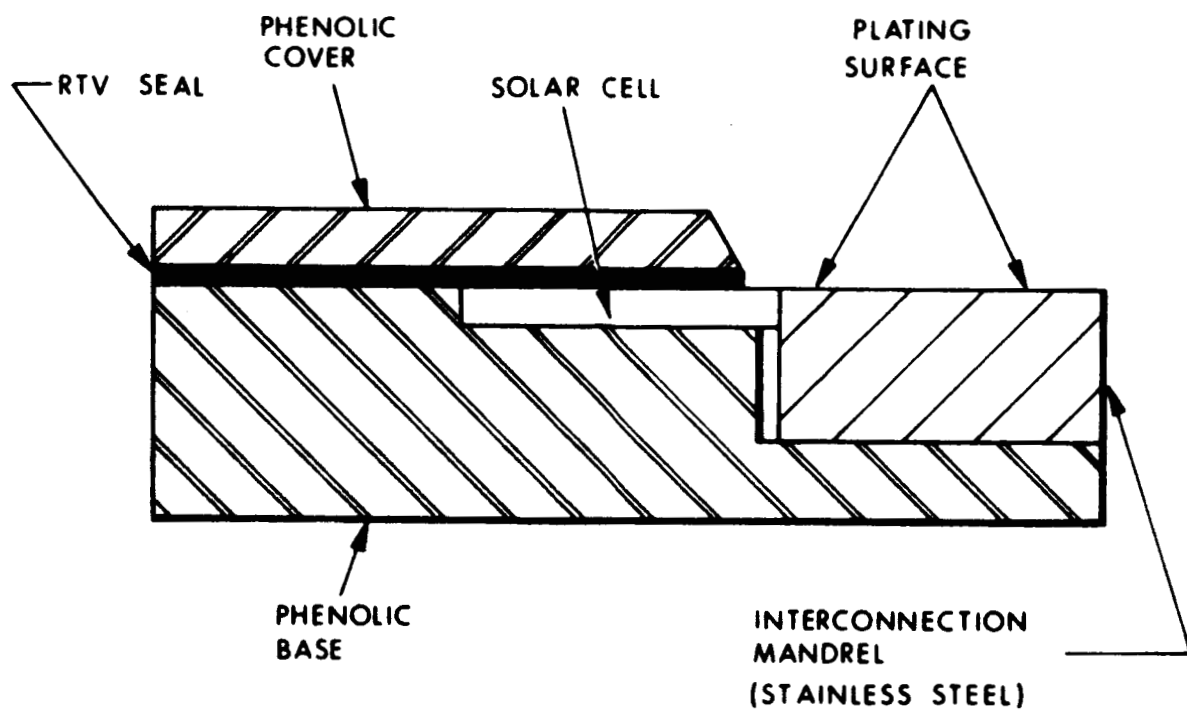


Figure 4. Single-Cell Plating Mandrel Concept



electroformed tabs were successful; as shown in Fig. 5, a continuous joint was obtained over the gap between the mandrel and the solar cell. Adhesion to the solar cell was good; (see Subsection 2.1.5.2). The difference in height between the cell and the tab was caused by a slight difference in height between the cell surface and the mandrel surface. This was corrected by machining the tab mandrel. (See photo of Fig. 6.)

Attempts to electroform a copper tab onto the cell again failed; in view of the successful results obtained with silver, further experiments with copper were abandoned. A typical wraparound solar cell with the electroformed tab is shown in Fig. 7.

The electroforming process produces an excellent tab on the solar cell, and cell performance changes appear to be minor. The silicon monoxide surface layer of the cell was etched somewhat during the process. This is likely a sealing problem which can be eliminated when the proper combination of sealing technique and material is found for the silver cyanide bath.

## 2.1.5 CELL TESTING

### 2.1.5.1 Electrical Tests

Standard test conditions were used for electrical testing of solar cells. These consist of illuminating the cell using a tungsten light source with an equivalent solar intensity of  $100 \text{ mW/cm}^2$  and a color temperature of  $2800^\circ\text{K}$ . The uniformity of light intensity is within  $\pm 1\%$  over the area of the cell. The electrical performance test fixture temperature is maintained at  $28 (\pm 2)^\circ\text{C}$  by using a controlled temperature water bath. The cell current output is measured at  $0.445\text{V}$ .

Figure 7 is a photograph showing a typical wraparound cell as well as a cell of the conventional type. Five wraparound cells and five



Figure 5. Photomicrograph of Solar Cell and Tab



Figure 6. Photomicrograph of Silver Electroformed Tab

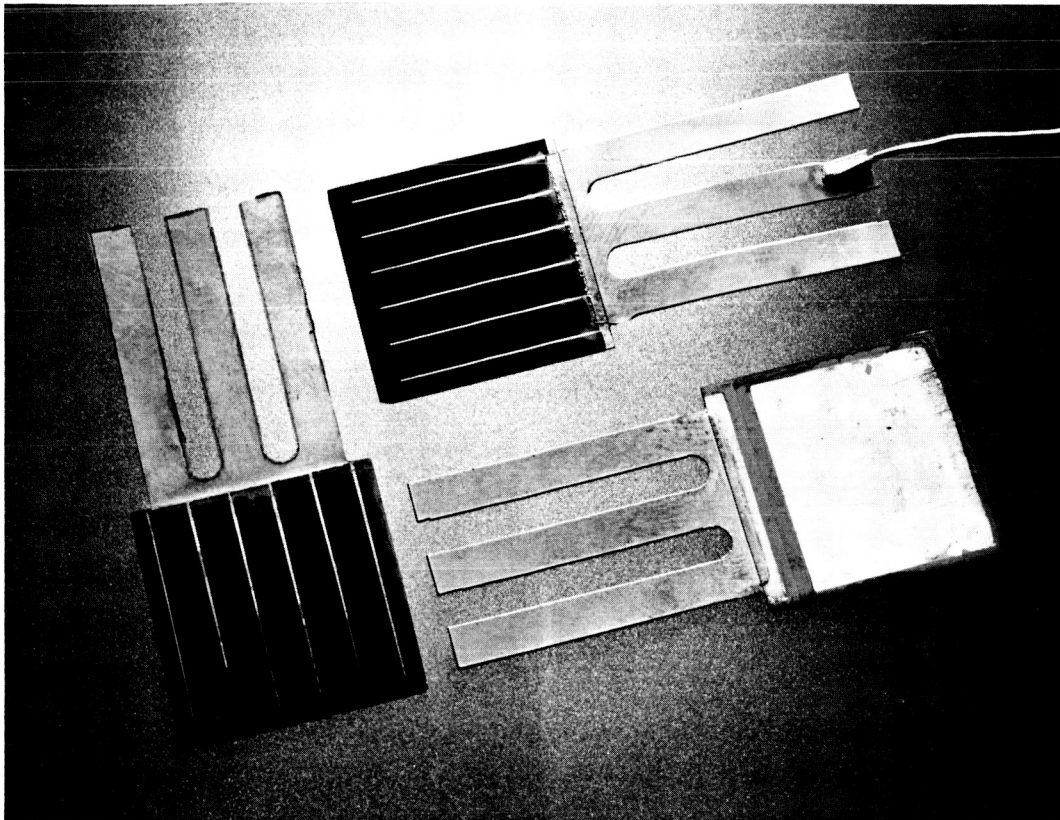


Figure 7. Photo Showing Typical Wraparound and Conventional Cells with Electroformed Tabs

conventional cells were electrically measured before and after the electroforming process. The cell performance changes are minor; the results are listed in Table III. The apparent increase in output of some cells is as yet unexplained, but is roughly within experimental error.

TABLE III  
CURRENT READINGS OF CELLS  
BEFORE AND AFTER ELECTROFORMING

Cell	Preelectroform Current	Postelectroform Current
1 Wraparound	98	97
2	94	94
3	95	95
4	99	97
5	95	97
1 Conventional	94	95
2	97	98
3	97	98
4	95	97
5	95	95

Cells were tested at a constant potential of 0.445V

#### 2.1.5.2 Physical Tests - N Contact Strength Test

The test objective was to determine the N contact adhesion strength after electroforming. A solid wire was soldered to the silver tab and increments of weight were added to the wire while the cell was held in a fixed position. On 10 cells, the contact supported a total weight of 1200 grams without failure. Cells were not tested to destruction. Tests were accomplished immediately after electroforming.

#### 2.1.5.3 Thermal Shock Test

The thermal shock test was performed to determine the ability of the new cell with electroformed silver contacts to withstand sudden temperature changes. The test was performed by immersing the cells into liquid nitrogen ( $LN_2$ ) for 10 seconds then immediately dipping them into boiling distilled water for 10 seconds. (This constituted one cycle of the test.) One single-cell and one two-cell module were subjected to the above tests. In all cases the cell broke after completion of the second thermal shock cycle; contact separation did not occur, however. The fractures were on a hypotenuse across the corner opposite the electroformed contact. Cause of fracture is unknown but it is suspected that rough handling introduced incipient cracks which became apparent upon thermal shock.

#### 2.2 TWO-CELL INTERCONNECTIONS

Based on the silver electroforming technology developed under Task I, a mandrel was designed and fabricated to electroform a two-cell interconnection. The basic concept is shown in Fig. 8. Special cells with minimum edge frames were mounted on the stainless steel interconnection mandrel. The phenolic ends and cover hold the cells in place approximately 30 mils apart. Three interconnections (0.050 x 0.004 inch) are then electroformed between the cells.

Several two-cell interconnections (Fig. 9) were electroformed using the two-cell mandrel. Again, good adherent interconnections were obtained as with the tabs on single cells. Physical and electrical tests showed the cells to be working properly, but the silicon monoxide surface layer was still being etched. Attempts were made to precoat the cells with Kodak metal etch resist (KMEK) and Minnesota Mining and Mfg. seal coat EC 2253 to prevent the etching of the silicon monoxide layer.

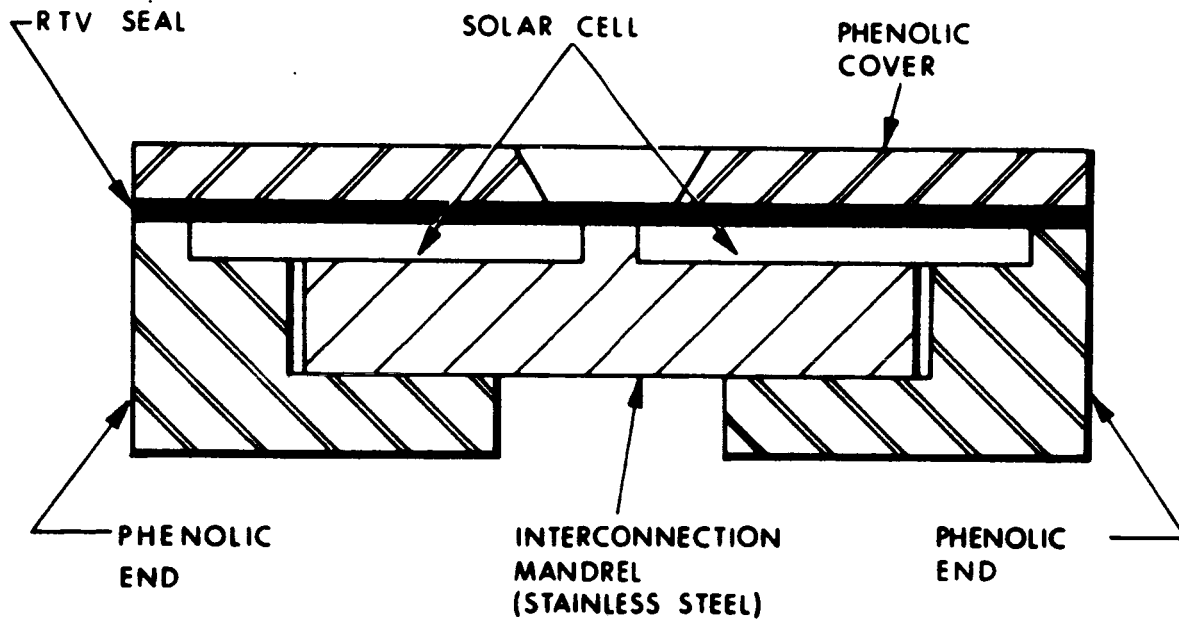


Figure 8. Two-Cell Mandrel Interconnections

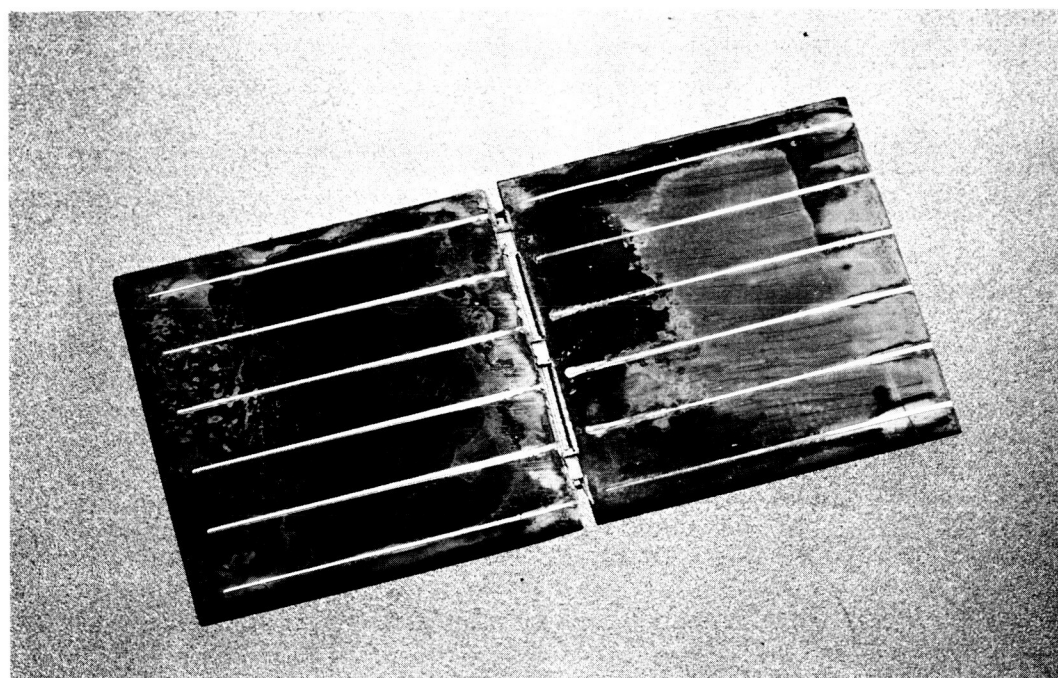
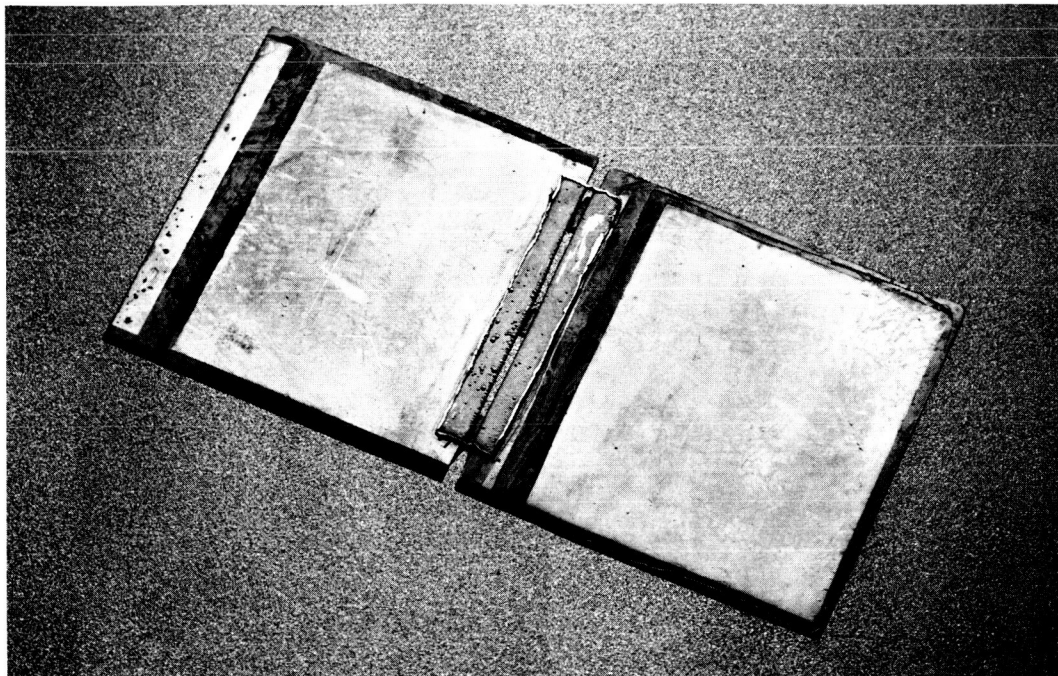


Figure 9. Two-Cell Combinations Using Electroformed Interconnections

Both coatings decreased the etching but were not fully effective. Studies were made to find a proper combination of materials and maskings to prevent the etching; however, no conclusive results were obtained.

### 2.3 FOUR-CELL INTERCONNECTIONS

This task extended the formerly developed techniques and processes to fabricate four-cell interconnections.

Design and fabrication of the four-cell mandrel was based on the one-cell and two-cell mandrel development study. The mandrels used for one-cell, two-cell, and four-cell module assembly are shown in the photographs of Figs. 10, 11, and 12. The detailed design layout is given in Figs. 13, 14, and 15. A sketch of the four-cell submodule is shown in Fig. 16. This design was selected as it readily lended itself to extension to submodules of larger size.

The mandrel was fabricated by machining stainless steel center and end pieces, leaving a raised plating surface at the location of the interconnections. An epoxy coating was then cast over the entire mandrel surface. The epoxy was then milled just the thickness of the cells below the raised stainless plating surfaces. This left a surface that was nonconductive at all points except where the interconnections were required. A phenolic-RTV masking cover was then fabricated to limit the electroforming to the desired areas on the surface of the cell. Electrical leads were cast into the cover to make contact with each solar cell to insure that the plating current would be fed into each cell. This is required so that the electroformed silver can grow from each surface and minimize the effects of gaps.



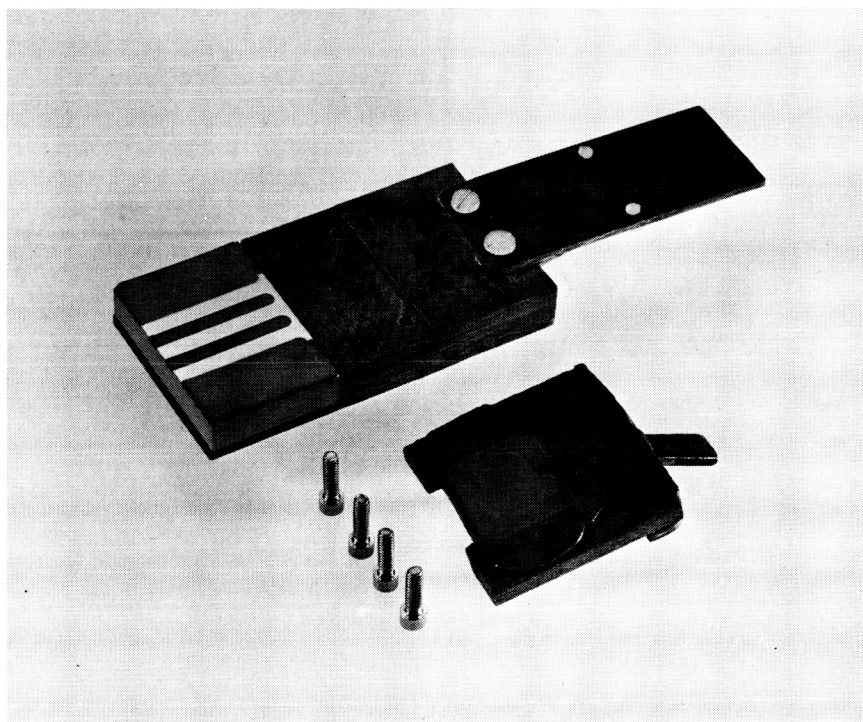
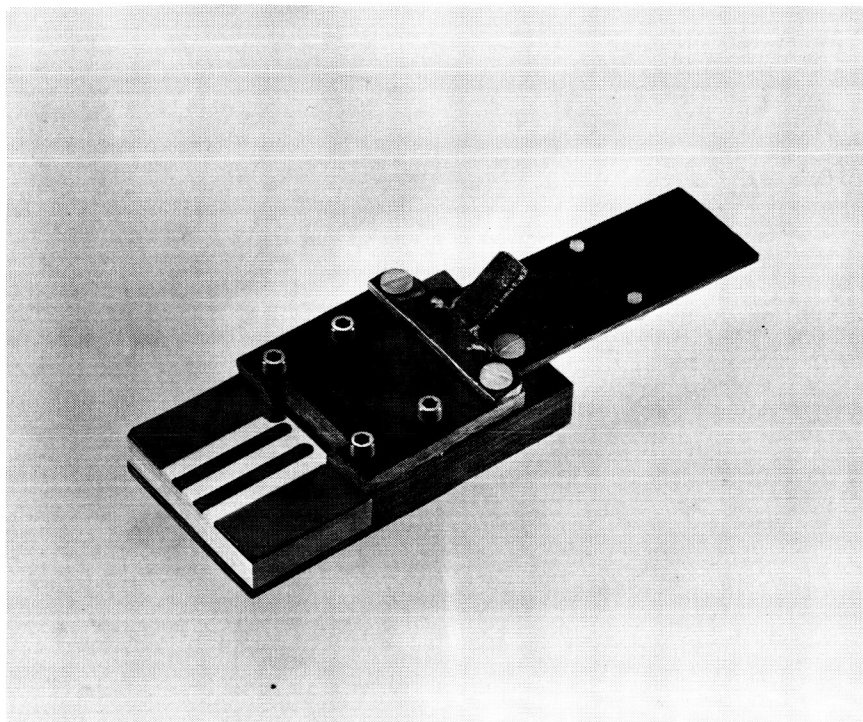


Figure 10. Single-Cell Plating Mandrel, Assembled and Disassembled

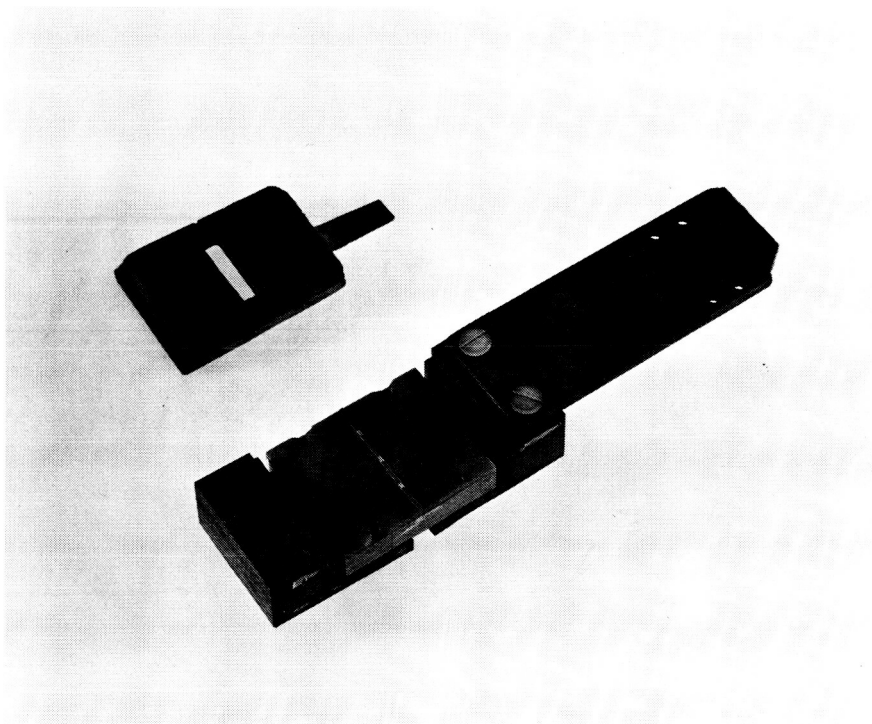
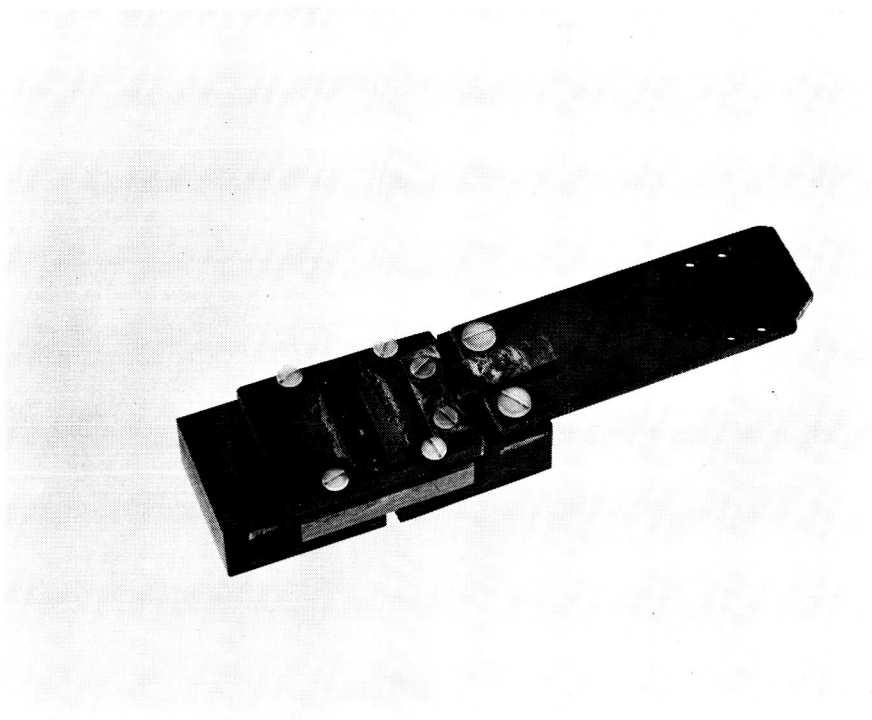


Figure 11. Two-Cell Plating Mandrel, Assembled and Disassembled

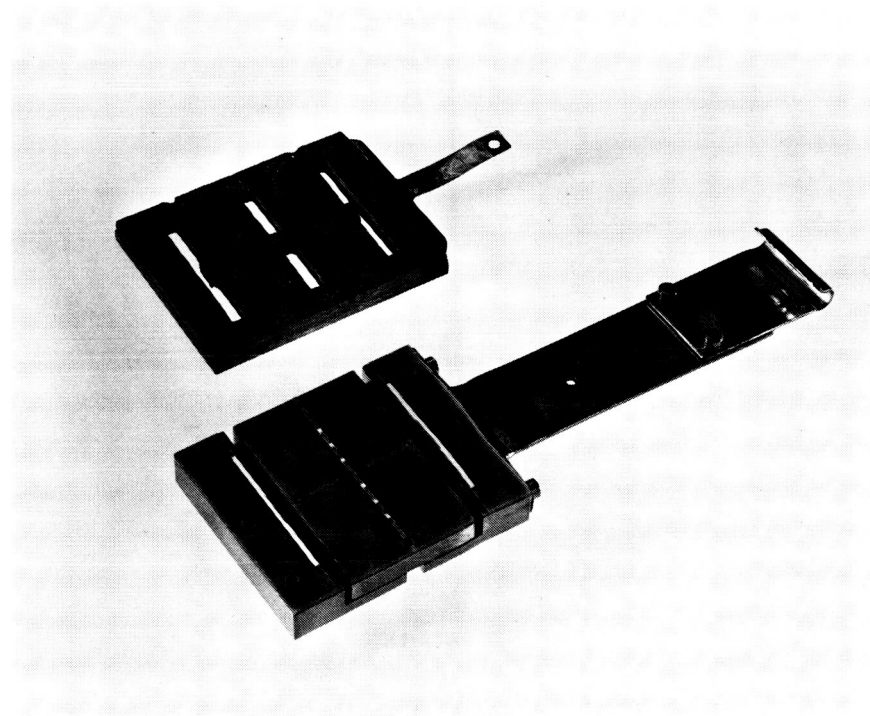
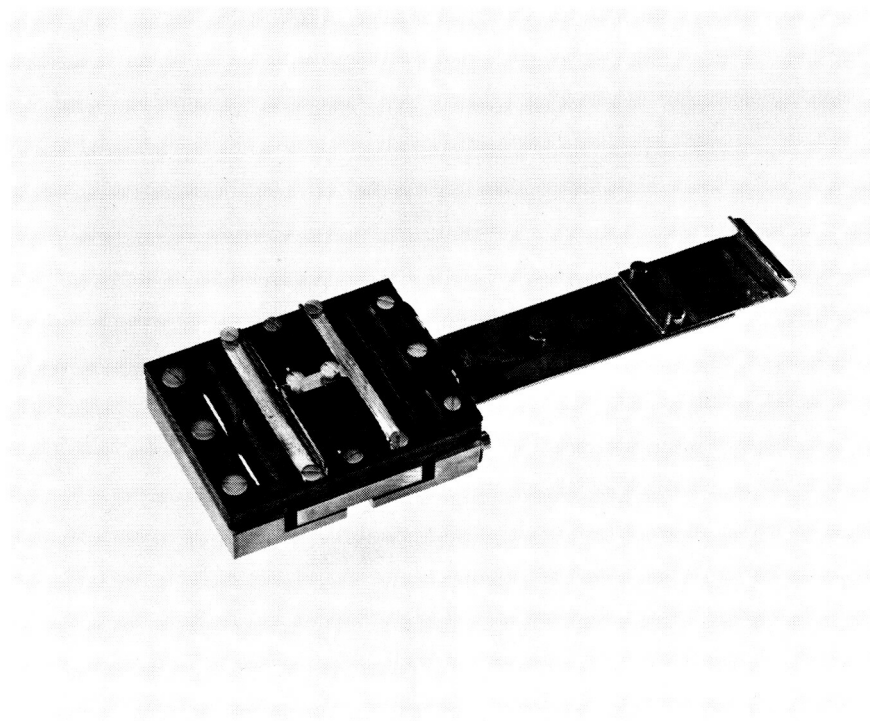


Figure 12. Four-Cell Plating Mandrel, Assembled and Disassembled

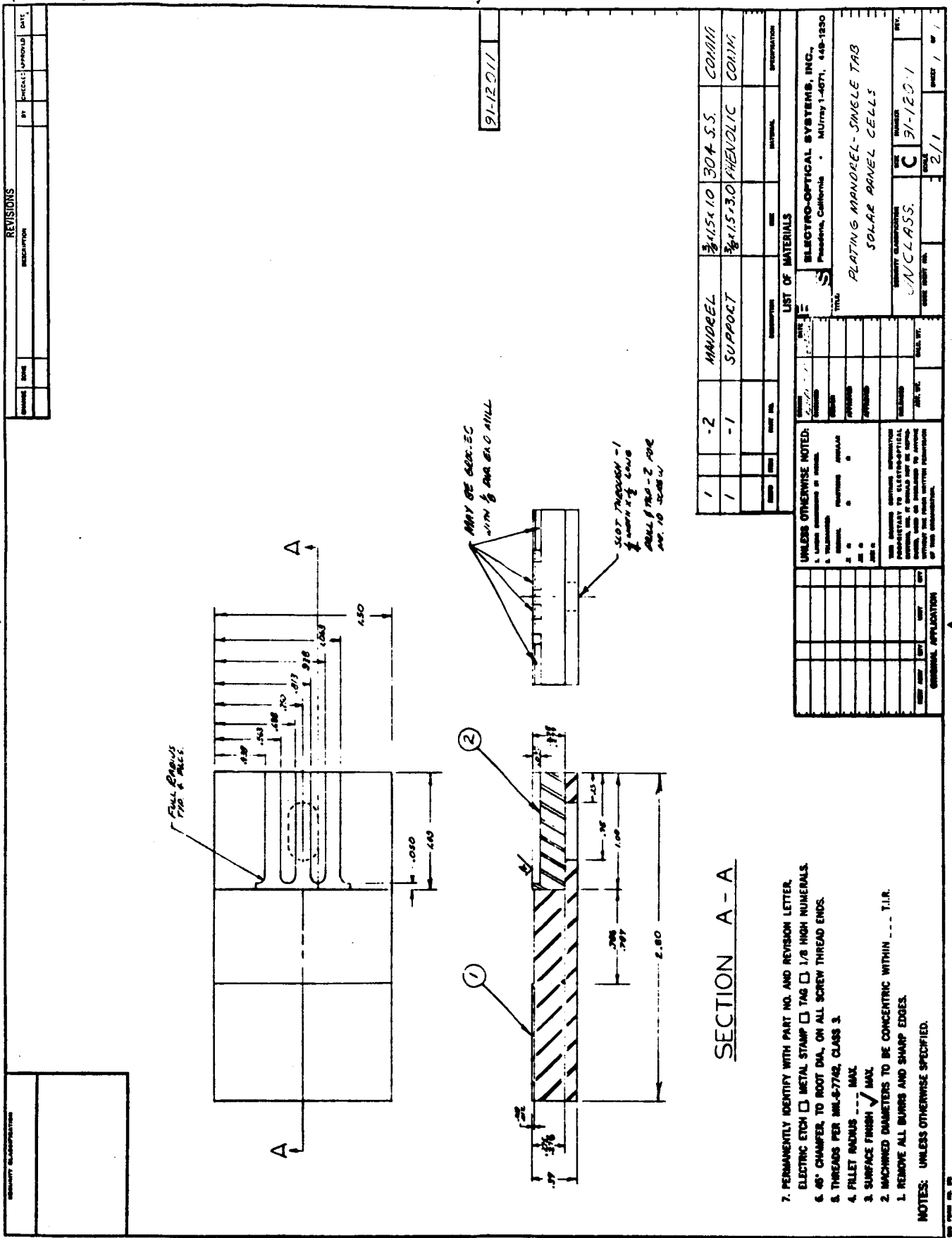
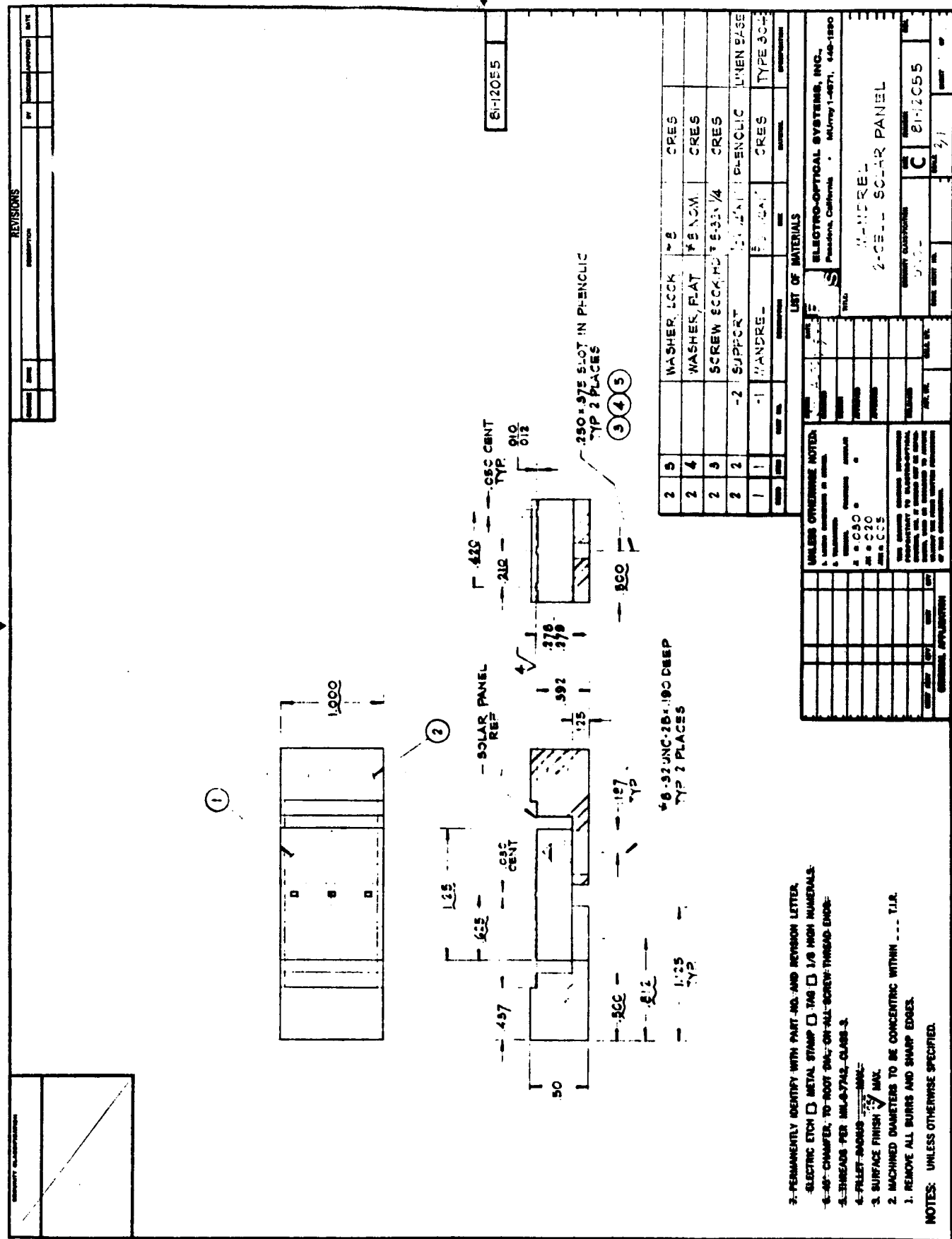
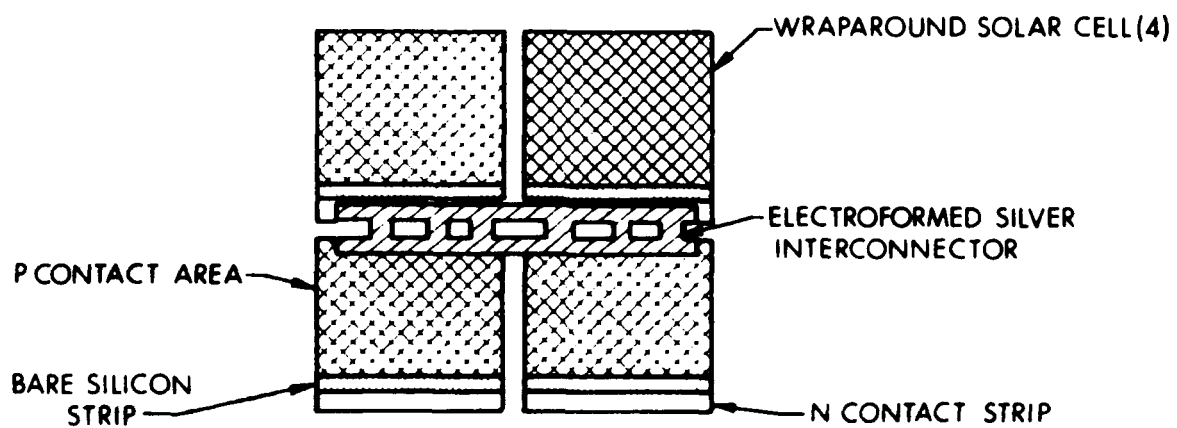


Figure 13. Single-Cell Plating Mandrel Drawing







### REAR VIEW

Figure 16. Electroformed Four-Cell Interconnection

Several additional holddown screws were added to the cover to increase the sealing pressure and minimize leakage which etched the two-cell modules.

Several cells having "picture frames" of less than 5 mils in width were selected for the initial platings. The cells were cleaned and electroformed. The interconnections were made successfully. However, when the module was being removed from the mandrel, the interconnections separated from the cells. Close examination revealed that the sintered silver-titanium contact had separated from the cell and remained attached to the electroformed silver. The remaining cells were tape-tested to evaluate the adhesion of the sintered contact to the cell. The contacts pulled off all cells except two. These cells were then set up in the two-cell mandrel and interconnected successfully.

Additional cells without the picture frame could not be obtained within a reasonable length of time, so it was decided to select several regular cells and lap off the window on one end. Several cells were lapped and subjected to the tape test. Those that passed the tape test were measured and arranged in groups of four, on the basis of size to minimize gapping.

Subsequent electroforming of these cells proved successful and 4 four-cell modules were electroformed. The adhesion of the interconnections to the cell was adequate but the surface of the cells was still somewhat etched.

#### 2.4 MULTICELL ELECTROFORMING CONCLUSIONS

Successful application of multicell techniques in fabrication of the four-cell modules clearly demonstrates that interconnections can be made between solar cells by the electroforming process. The process specification by which these cells were interconnected is presented in Appendix II.



#### 2.4.1 CELL QUALITY REQUIREMENTS

Successful interconnection of the solar cells by electroformed contacts required that the cells have the following special characteristics:

- The wraparound cell design allows the N and P connections to be made on the same side of the cell; this greatly simplifies the electroforming mandrel and masking design.
- The picture frame around the cell must be no greater than 5 mils in width. The electroformed silver will not grow across nonconductive surfaces greater than 5 mils.
- Cell dimensions should be maintained as close as possible to some given norm. Variations in length and width allow the cells to misalign when mounted in rows or columns for electroforming. Cell tolerances of  $\pm 0.002$  inch appear reasonable; however, most cells are ordered to  $\pm 0.005$  inch tolerances at present and the increased cost must be investigated.
- Adherence of the sintered silver-titanium contact to the cell must be carefully controlled. Most of the failures encountered in the initial phases of the development program have occurred when the sintered silver-titanium separated from the cell after the electroforming process. Adhesion of the electroformed silver to the sintered contact was generally good.

#### 2.4.2 ACTIVATION OF CELLS

To obtain good adhesion between the electroformed silver and sintered silver-titanium contact, the passive surface layer on the cell must be removed by activation. This process is currently being performed before the cells are mounted in the electroforming fixture. This prevents the stainless steel mandrel from being activated along with the cell and the silver adhering to the mandrel. Additional mandrel materials should be evaluated to find a material which would allow the cells to be activated in the fixture while still not activating the mandrel surface.

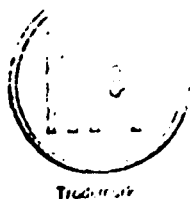
#### 2.4.3 MANDREL DESIGN REQUIREMENTS

The initial program definitely established that success of the electroformed tabs depends upon accurate mandrel design and fabrication. The mandrel must be designed to have some adjustment to allow for variations between cell dimensions so that gaps and misalignments can be minimized. Before production tooling can be fabricated, several mandrel and masking materials should be evaluated to determine which have the most desirable properties for the silver electroforming bath.

Careful integration of design and material selection should produce a workable production process for reliably producing interconnected sub-modules.

APPENDIX I

SILVER-LUME BRIGHT SILVER PLATING PROCESS



## SILVER-LUME\* BRIGHT SILVER PLATING PROCESS†

A practical process for depositing a truly bright silver directly from the solution has been the goal of silver platers for many years. The Silver-Lume process is the first practical solution developed for producing brilliant and mirror-like deposits, eliminating in many cases any need for buffing after plating.

### ADVANTAGES

1. Brilliant deposits
2. Increased tarnish resistance
3. Increase in hardness of deposit means greater wear resistance (55 VHN for regular silver vs. 110 VHN for the Silver-Lume deposit)
4. High current densities possible
5. Wide current density range
6. Non-critical operation and control
7. Economical bath operation
8. No accumulation of deleterious brightener decomposition products
9. Reduction of finishing cost up to 60%
10. Pure silver deposits—not an alloy
11. High electrical conductivity
12. Increased adhesion of deposit
13. Exceptional throwing and covering power
14. Increased protection against corrosion of base metal

### SOLUTION PREPARATION

The recommended solution composition is as follows:

	oz./gal.	lbs/100 gal.
Silver cyanide	6.0	37.5
Potassium cyanide	15.0	94.0
Potassium carbonate	3.0	18.75
Silver-Lume Brightener A	0.32	2.0
Silver-Lume Brightener B	0.25% by vol.	1 quart

\*Trademark of M&T Chemicals Inc.

†U.S. Patent No. 2,666,738

After the bath has been prepared, the analysis of the bath should show the following concentrations:

	oz./gal.
Silver metal	5.0 -
Free potassium cyanide	12.0
Potassium carbonate	3.0 to 10.0

The solution may be prepared either in the plating tank or, preferably, in an auxiliary tank of suitable size. Place an amount of water in the make-up tank equal to about half the final solution volume and dissolve in this the calculated amounts of potassium cyanide and potassium carbonate. When these constituents are completely dissolved, add the silver cyanide slowly with constant stirring to insure complete solution.

The two pounds of Silver-Lume Brightener A required to prepare 100 gallons of solution *are not added directly to the bath* but are prepared by stirring with 2 gallons of water containing 21 ounces of potassium hydroxide. Stir well and, if possible, allow the brightener solution to stand overnight before adding it to the plating solution. Add brightener through filter or anode bag.

Silver-Lume Brightener B, a liquid, mixes readily with the plating solution and may be added directly to the bath.

### Toxicology—Industrial Hygiene

As with all materials containing cyanides, which may cause systemic effects if taken internally in addition to eye and skin irritation, it is necessary to prevent accidental swallowing, contact with eyes, skin, and clothing. Also, these solids or their solutions are absorbed through the skin and can cause skin burns because of hydrolysis to alkalis.

If these materials are accidentally allowed to come in contact with acids, poisonous gases may be liberated. Therefore, if this possibility exists, workmen should be provided with and instructed to use approved gas masks for hydrocyanic acid gas.

(over)

HANSON-VAN WINKLE-MUNNING DIVISION  
**M&T CHEMICALS INC.**  
GENERAL OFFICES: RAHWAY, NEW JERSEY 07065

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#### **Suggested First Aid**

If accidentally swallowed, immediately consult a physician on use of amyl nitrite capsules or pearls and cyanide antidote.

In the event of inhalation of gas from accidental reaction of material with acid, remove to a non-contaminated area and immediately consult a physician on use of amyl nitrite capsules or pearls.

In the case of eye contact, thoroughly wash out eyes with a continuously flowing stream of water directed into the eyes for at least 15 minutes. Consult a physician.

Skin exposure should be followed by a thorough rinsing with water.

#### **SOLUTION PURIFICATION**

As with all bright plating solutions, care should be taken to work with materials and equipment of good quality. All tanks and equipment coming in contact with the bright silver solution should be cleaned well before use.

After making up the solution as described, it should be allowed to stand for a day or two before finally filtering it into the plating tank. This will assure bright deposits initially. Filterbestos C-75 should be used on the filter pads rather than the commonly used diatomaceous earth filter aids. Occasionally, optimum results are obtainable only after the bath has been in operation from three to five days.

#### **CONVERSION OF EXISTING BATHS**

Most existing silver baths can be converted to the Silver-Lume process. Occasionally, however, such baths require special treatment, e.g., a purification with activated carbon to remove undesirable organic impurities. Old baths that are high in sodium salts (especially sodium carbonate) may require increased concentrations of both, Silver-Lume Brightener A and Brightener B initially, followed by aging for several days, in order to obtain a wide and uniform bright range. With high sodium baths, a light, oily film may be formed on the surface of the bath after the brighteners have been added. This is not harmful. After the aging as described above, this film can be removed by filtration. Carbonate removal with calcium nitrate is often beneficial. (Approximately 1.7 ounces of calcium nitrate crystals  $[\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}]$  will remove 1 ounce of potassium carbonate). Silver-Lume baths should be maintained only with *potassium* cyanide and *not with sodium* cyanide, as potassium salts have a favorable influence on the bright current density range whereas sodium salts in high concentrations exert a salting-out effect on the brighteners. When converting from sodium to potassium solutions, it is usually desirable to add 12 to 14 ounces per gallon of potas-

sium nitrate. It is suggested that whenever it is desired to convert a solution already in use, a sample consisting of not less than one full quart should be sent to the service laboratory of M&T Chemicals Inc., 100 Church Street, Matawan, New Jersey 07747, so that specific instructions for converting the solution can be provided.

#### **EFFECTS OF CONSTITUENTS**

Although the composition of the Silver-Lume solution is by no means critical, it is advisable to maintain the silver metal and free cyanide content reasonably close to the optimum values previously given.

##### **Silver Cyanide**

This compound furnishes the silver ions to the solution. The silver content should be held at, or above, 4.5 ounces per gallon. A higher silver content, e.g., 6 ounces per gallon, permits higher current densities to be used. Further additions of silver cyanide are needed only occasionally, to compensate for drag-out losses, providing the anode area is sufficient.

##### **Potassium Cyanide**

The free potassium cyanide content should be held as near to 12 oz/gal. as possible at normal silver concentrations, because this is an important factor in maintaining proper operating conditions. If the free cyanide falls too low, the bright plating range contracts and the deposits lose some of their normal brilliance. An excess of free cyanide is not harmful but obviously wasteful. Do not use *sodium* cyanide for maintenance.

##### **Potassium Carbonate**

As in all cyanide solutions, the carbonate content gradually builds up considerably above the starting value. Experience indicates that there is no sharp critical limit, but over 14 oz/gal., cloudiness may be evident in low current density areas.

##### **Silver-Lume Brightener A**

This is the dominant factor in producing bright deposits. Silver-Lume Brightener A is not completely soluble in water but is soluble in alkaline solutions. It is best dissolved in a solution of potassium hydroxide (10.5 ounces per gallon) in the proportion of 1 ounce of Brightener A per 8 fluid ounces of the caustic potash solution. Allowing the solution to stand overnight is helpful in producing a clearer solution. The brightener stock solution should be made up so it will be consumed within one week. *Direct addition to the bath of Silver-Lume Brightener A, without prior neutralization with potassium hydroxide, must be avoided.* A considerable excess of potassium hydroxide above the amount required for neutralization of the Silver-Lume Brightener A

tends to produce milky deposits on the low current density areas.

Silver-Lume Brightener A is replenished on the basis of Hull Cell or equivalent plating tests. Additions required will be between 2 and 8 ounces per 100 gallons of solution per week. Small additions at frequent intervals are preferred to larger additions at one time.

#### Toxicology—Industrial Hygiene

Silver-Lume Brightener A may cause systemic effects if taken internally and care should be taken to avoid accidental swallowing. This product has been found to be irritating to the skin and eyes and it is advisable to take appropriate measures to protect workmen from eye and skin contact. The use of respirators, protective clothing, chemical goggles, and rubber gloves by workmen handling this material is recommended.

Silver-Lume Brightener A tends to dust and this dust has been found to be irritating to the respiratory system as well as to the skin and eyes.

#### Suggested First Aid

In the event of eye contact, flush out eyes thoroughly with water for 15 minutes. This is best done by means of a continuously flowing stream of water directed into the open eyes. A physician should then be consulted. In the case of skin contact, remove contaminated clothing and drench the skin thoroughly with water for 10 to 15 minutes. Contaminated clothing should be laundered before re-use.

If Silver-Lume Brightener A is accidentally swallowed, a physician should be consulted immediately.

#### Silver-Lume Brightener B

This is an auxiliary addition agent which enhances the effect of Silver-Lume Brightener A. Silver-Lume Brightener B is remarkably stable and apparently is lost only through drag-out. Therefore, it should be replenished when the Hull Cell results indicate the need for additions. An excess of Brightener B produces deposits that are hazy in low current density areas. Like Brightener A, Brightener B is added only on the basis of plating tests (with Hull Cell or equivalent). Conditions of operation vary so widely that an exact replacement figure cannot be given; however, it is suggested that the quantity required will not be over one fluid ounce (approximately 30 ml.) per 100 gallons per week.

When either Silver-Lume Brighteners A or B are first added, plating tests made immediately after the additions are not representative of the results after the solution has aged. Allow the solution to stand overnight (12 hours) before making final judgment of the effect of such additions.

## OPERATING CONDITIONS

### Current Density

The Silver-Lume process may be operated over a wide range of current densities and gives fully bright deposits at current densities higher than those used in most silver plating operations. The permissible current density depends principally on the metal content, the temperature, and the degree of agitation. High metal content, high temperature, and vigorous agitation permit the maximum current to be used. Of these, temperature is perhaps the most important factor. Specific current density recommendations are given in Table I, at right. The relationship between current density and thickness of deposit is shown in Table II, below.

### Temperature

The temperature may vary from room temperature (preferably not under 70°F) up to 120°F. The main consideration in choosing a working temperature is the current density one wishes to employ as shown in Table I.

TABLE I

Temp. Range (°F)	C.D. (max. ASF)
70 to 75	10
80 to 85	15
95 to 100	35
115 to 120	60

The foregoing values apply specifically to a solution containing 4.5 oz/gal. of silver and moderate cathode rocker agitation. A higher silver content and more vigorous agitation permit even higher current densities.

### pH Level

A freshly prepared Silver-Lume solution will have a pH (electrometric) of approximately 12.1. Although this factor is not critical, it is suggested that the pH be maintained between 11.0 and 12.5. pH changes within this range have little effect, but at values above 12.5, milky deposits may appear in the low current density areas.

The pH can be lowered by cautious addition of potassium bicarbonate.

**CAUTION:** Some hydrocyanic acid fumes may be released by this treatment. **AVOID BREATHING FUMES.** Use adequate ventilation since hydrocyanic acid fumes are flammable.

(over)

**TABLE II**  
**Deposit Thickness vs. Time†**  
**(In minutes and seconds)**

Thickness (inch)	Amperes per Square Foot						
	5	10	20	30	40	50	60
0.0001	7:24	3:42	1:51	1:14	0:56	0:45	0:37
0.0002	14:48	7:24	3:42	2:28	1:51	1:29	1:14
0.0003	22:12	11:06	5:33	3:42	2:47	2:13	1:51
0.0004	29:36	14:48	7:24	4:56	3:42	2:58	2:28
0.0005	37:00	18:30	9:15	6:10	4:38	3:42	3:05
0.0006	44:24	22:12	11:06	7:24	5:33	4:26	3:42
0.0007	51:48	25:54	12:57	8:38	6:29	5:11	4:19
0.0008	59:12	29:36	14:48	9:52	7:24	5:55	4:56
0.0009	66:36	33:18	16:39	11:06	8:20	6:40	5:33
0.001	74:00	37:00	18:30	12:20	9:15	7:24	6:10
0.002	148:00	74:00	37:00	24:40	18:30	14:48	12:20

†Based on 100% cathode current efficiency

### Heating

The solution may be heated by means of a stainless steel coil (type 304, 316, 347, Carpenter 20) Karbate immersion heater. If a metal coil is used, it should be placed between the anodes and the side wall of the tank and should not extend beyond the anodes either at the sides or at the bottom of the tank. It should be placed so that it is electrically shielded by the anodes.

### Agitation

Relative motion between work to be plated and the Silver-Lume solution is beneficial, especially when high current densities are used. Sufficient agitation is obtained in most cases by cathode rocker motion or even by the normal motion in a conveyor. For more vigorous agitation and maximum speed of plating, propeller agitation or submerged solution circulation is recommended. Because of foaming, air-agitation cannot be used.

### Filtration

The importance of keeping the solution free from suspended matter can hardly be over emphasized if bright deposits, free from roughness at all times, are to be obtained. Where the solution is not vigorously agitated so that suspended matter is given an opportunity to settle to the bottom of the tank, periodic filtration will suffice. The filter should be stainless steel or covered with a suitable coating; the pump should be of stainless steel.

### Anodes

Silver anodes of best quality should be used. In general, there is no difference in the behavior of the anodes in this solution and in the ordinary silver plating solution. It should be noted that a larger anode area may be required, and replacement made more frequently, when operating at the higher current densities possible with the Silver-Lume process.

### Anode Bags and Diaphragms

Keeping the solution clean is important. The use of either anode bags or diaphragm boxes around the anodes is an essential step in preventing insoluble matter from the anodes entering the solution. Anode bags or diaphragms should be made of nylon NW synthetic fabric. A simple anode diaphragm box to take care of all the anodes on one anode bar or a group of such anodes is preferred to separate anode bags. An anode box can be constructed from welded 1/4" steel rod insulated with Unichrome® Rack Coatings Super 218-X or 218-X, Unichrome Tape 705, or Wrap-Rax® Tape, all available from M&T. The entire frame is encased in a bag made of the nylon NW material. So that the anodes do not come into contact with the fabric, and to permit good solution circulation within the box, it is suggested that the box be two inches wide with the length and depth selected to accommodate the length and number of anodes.

### Anode-Cathode Spacing

The distance between the anodes and the work is governed by the size and shape of the pieces to be plated. Recommendations regarding this spacing for specific articles will be made on request.

### Racks

Work racks should be sturdily made with thick enough cross sections to carry the current to all parts without excessive heating. At higher current densities especially, care must be exercised to make sure that all contacts handle their proper share of the current. Racks should be coated with a good rack insulating material such as Unichrome Rack Coatings Super 218-X or 218-X, Unichrome Tape 705, or Wrap-Rax Tape, all available from M&T.

\*Trademark of M&T Chemicals Inc.

### Tanks

Lined (e.g., vinyl or rubber) tanks are recommended. Steel tanks are not recommended because the build-up of ferrocyanide in the solution will lower the current efficiency. Linings used for the Silver-Lume process should be of a type approved by M&T.

### Water

Exceptionally hard water should not be used for make-up or replenishment since calcium and magnesium salts may precipitate out and cause rough deposits. Water deionized by treatment with ion exchange resins should be used only after water-soluble matter in the resin has been extracted. This precaution is necessary only with a new resin bed. After one or more regenerations there is no further danger of picking up deleterious impurities.

### Rinsing

As bright silver deposits are not usually buffed, it is desirable to rinse and dry in a manner that will not cause staining. A rinse aid added to the final hot water rinse may be helpful.

### STRIKE SOLUTION

Preparation of articles for plating in the Silver-Lume process is the same as preparation for ordinary silver plating. A silver strike is recommended prior to plating with the Silver-Lume process.

A strike bath may be made up as follows:

Silver cyanide	0.4 to 0.6 oz/gal.
Potassium cyanide	11.0 to 14.0 oz/gal.

Because of the relatively high free cyanide carried in the Silver-Lume bath, many users have reported that the customary strike can be eliminated. Although it is acknowledged that satisfactory adhesion has been obtained on a considerable amount of work processed in this manner, it is nevertheless a safer procedure to use a strike. Bear in mind, however, that the minimum voltage and time should be employed in the strike for brightest final deposits. Where the strike has been operated at 5 to 6 volts for 15 to 25 seconds in a non-bright bath, it is suggested that only 3 to 4 volts be used for 8 to 12 seconds in preparation for plating with the Silver-Lume process.

### IMPURITIES AND THEIR REMOVAL

All chemicals used should be of good quality. Even so, some purification may be necessary when the solution is first made up and further purification may prove necessary from time to time as impurities accumulate. Some types of impurities are most effectively removed by treatment with an approved grade of activated carbon. Activated carbon treatment partially removes the brighteners. After carbon treatment, the brighteners must be replenished.

### BARREL PLATING WITH SILVER-LUME

The Silver-Lume process is used extensively for bulk plating by the barrel method. In general, the same composition is used as in still plating, though sometimes with a lower metal concentration in the interest of economy.

The voltage employed varies between 4 and 5 volts with standard horizontal cylinders. In many cases, a preliminary strike has not been found to be necessary although this should be checked with the particular surfaces being plated.

### ACTIVATING SILVER-LUME DEPOSITS

Silver-Lume deposits, as indicated by their tar-nish-resistant properties, are slightly passive and should be activated prior to subsequent plating operations.

When mechanical polishing and buffing operations are not used, the surface can be activated by dipping for 1 to 2 minutes in a 6 oz/gal. solution of potassium hydroxide, or by cathodic treatment for 30 to 60 seconds in a 3 to 4 oz/gal. solution of potassium cyanide.

### ANALYTICAL PROCEDURES

The following procedures are reproduced from "Simple Methods for Analyzing Plating Solutions," available from M&T.

Methods for making and standardizing the solutions for these procedures can be found in any good text on quantitative analysis. The coded solutions can be purchased in convenient quantities from M&T Chemicals Inc.

#### SM-7: Carbonate in Cyanide Solutions

1. Pipette a 10 ml. sample into a 250 ml. beaker.
2. Add with a graduate 100 ml. of distilled water.
3. Heat the contents of the beaker and add, while stirring, 25 ml. of AR-23 (barium nitrate). Allow the precipitate to settle and add a few more drops of AR-23 to make sure the precipitation is complete.
4. Using filter paper and a funnel, filter the contents of the beaker, and thoroughly wash the beaker and filter three times with hot distilled water, collecting the clear filtrate and washings in a clean beaker or Erlenmeyer flask. Save this filtrate if free cyanide is to be determined by Test SM-11.
5. Place the filter paper and precipitate in the original beaker and add about 50 ml. of distilled water and 5 drops of AR-24 (methyl orange indicator).
6. Fill a 50 ml. burette with AR-25 (1N hydrochloric acid) and titrate, stirring constantly, until a permanent pink color is obtained.



7. Read the burette. The ml. of AR-25 used, multiplied by 0.71 gives ounces of sodium carbonate, or multiplied by 0.93 gives ounces of potassium carbonate, per gallon of plating solution.

#### SM-11: Free Cyanide in Cyanide Solutions

NOTE: This test is not applicable to cadmium and zinc cyanide solutions.

1. Perform steps 1, 2, 3 and 4 of Test SM-7, Carbonate in Cyanide solutions.
2. To the filtrate and washings from Step 4, add with a graduate 5 ml. of AR-14 (potassium iodide).
3. Fill a 50 ml. burette with AR-6 (0.1N silver nitrate) and titrate until a faint yellowish turbidity remains while stirring or swirling.
4. Read the burette. The ml. of AR-6 used, multiplied by 0.131 gives ounces of sodium cyanide, or multiplied by 0.174 gives ounces of potassium cyanide, per gallon of plating solution.

#### SM-14: Silver in Silver Cyanide Solutions

1. Pipette a 10 ml. sample into a 250 ml. beaker.
2. Add 50 ml. of distilled water and warm.

3. Add 20 ml. of AR-36 (sodium sulfide).
4. Stir the warm solution for a few minutes to coagulate the brown precipitate.
5. Filter through paper and wash with hot water.
6. Fold the paper containing the precipitate and transfer it to a 250 ml. Erlenmeyer flask.
7. Add 5 ml. of AR-18 (nitric acid) and boil under a hood.
8. Moisten the paper with about 2 or 3 ml. of water, from time to time as necessary, until the brown precipitate has been dissolved and no more brown fumes are evolved.
9. Add 50 ml. of distilled water and about 2 ml. of AR-37 (ferric alum).
10. Fill a 50 ml. burette with AR-38 (0.1N sodium thiocyanate), and titrate the solution until a faint red color remains while shaking.
11. Read the burette. The ml. of AR-38 used, multiplied by 0.144 gives the avoirdupois ounces of silver per gallon of plating solution.

### Brightener Control

Additions of brightener should be made at regular intervals on the basis of tests made with a Hull Cell. If the analysis for silver and free cyanide is within the recommended range, the Hull Cell is used first to determine the optimum addition of Silver-Lume Brightener A by adding small amounts in increments of about 0.05 oz./gal. from a freshly prepared stock solution until the maximum bright plating range is obtained. It may be possible to obtain a higher luster by making

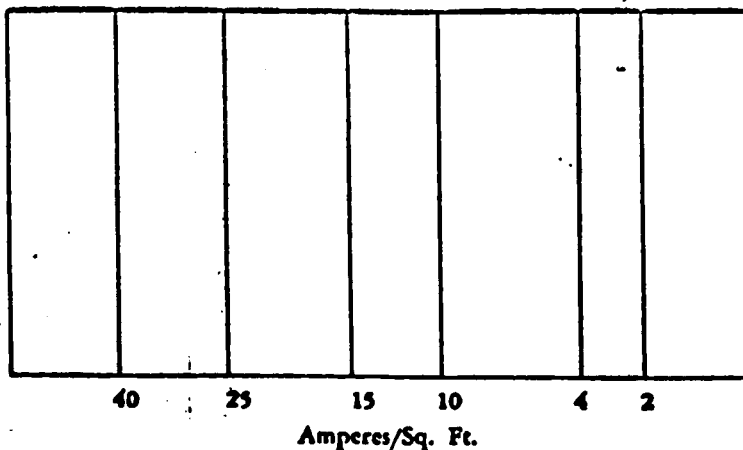
successive small additions of Silver-Lume Brightener B on the order of 0.02 fluid ounces per gallon until no further improvement is obtained. However, additions of Brightener B will not be required as frequently as additions of Brightener A. These conditions are all covered in the following charts. Note that several hours aging of the test solution brightener addition will give a truer indication of the effect of the addition.

# OPERATING CONDITIONS FOR PLATING TESTS

Standard Hull Cell	267 ml. Capacity	Time	10 minutes
Room Temperature	80° F.	Agitation	None
Total Current	One Ampere	Anode	Silver
Voltage	Approx. 1.6 to 2.0 Volts	Cathode	Polished brass panel, silver-flashed.

## HULL CELL PANEL (Full Scale)

1.0 Ampere Total Current



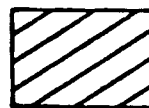
## KEY TO FOLLOWING CHARTS



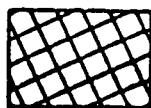
Bright



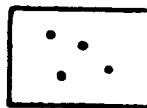
Streaked



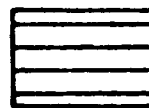
Dull



Burnt  
Rough,  
Powdery



Pitted

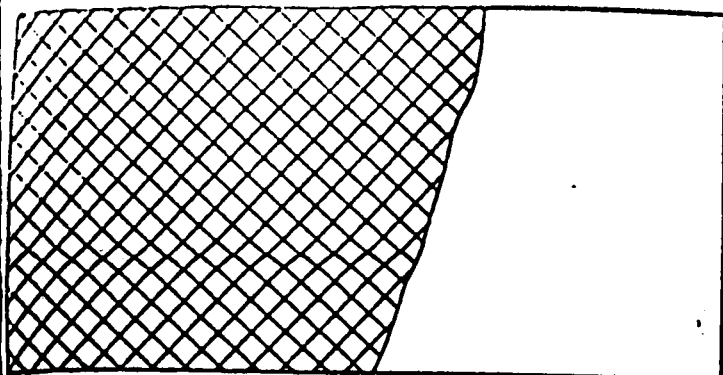


Semi-Bright

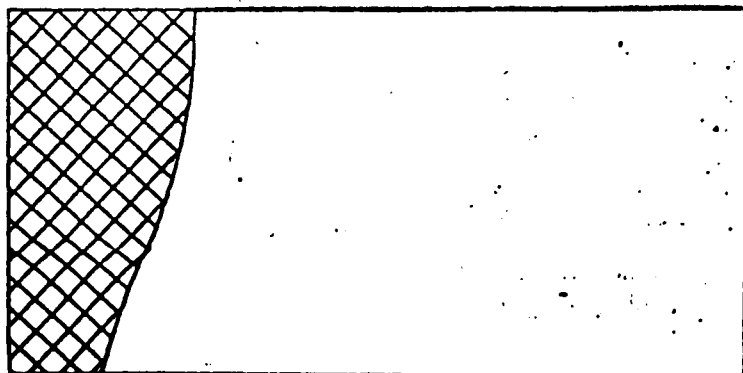


# SILVER-LUME PROCESS—PLATING TESTS

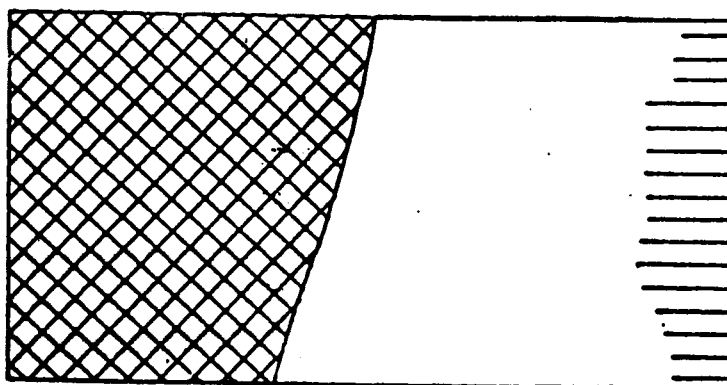
With Unbalanced Silver, Normal Free Cyanide, and Carbonate Concentration



**Low Silver Content, Normal A and Normal B Concentration**  
Remedy: Adjust metal content to formula.

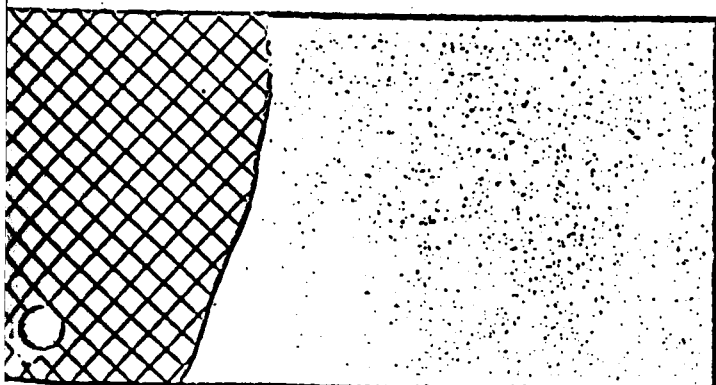


**Higher Silver Content, Normal A and Normal B Concentration**

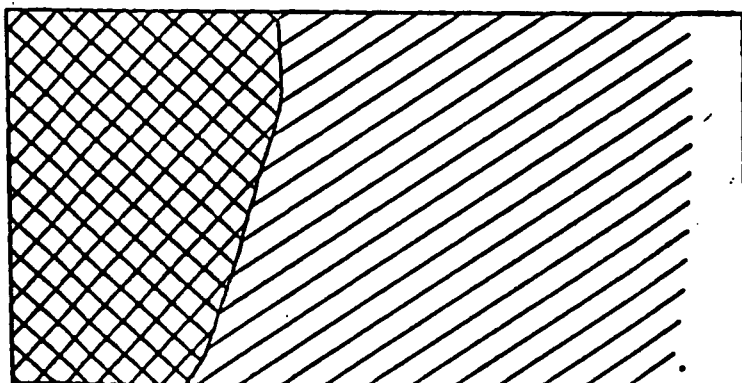


**Low Free Potassium Cyanide Content, Normal A and Normal B Concentration.**  
Remedy: Adjust to formula.

## EFFECT OF IMPURITIES

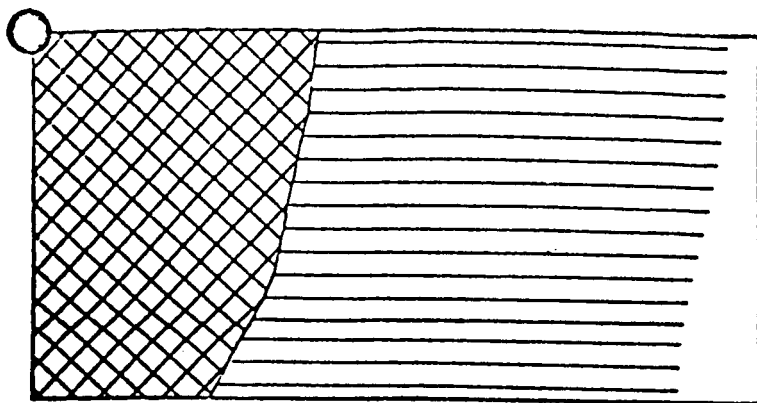


**Salt and Pepper Effect: Normal A and B Concentration**  
Remedy: Filtration and electrolysis.

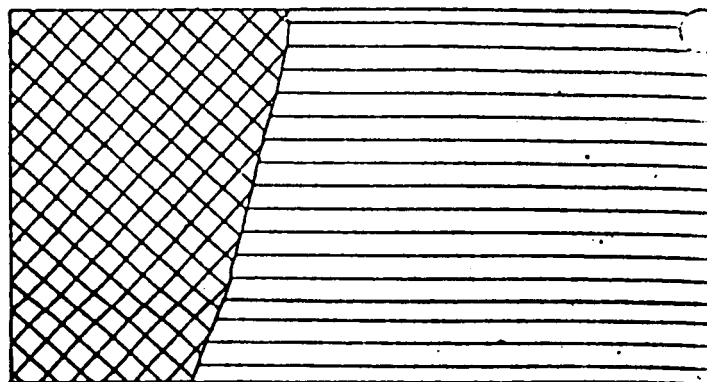


**High Sodium Ion Concentration, Normal A and B Concentration**  
Remedy: Add 8 to 16 oz/gal. potassium nitrate.

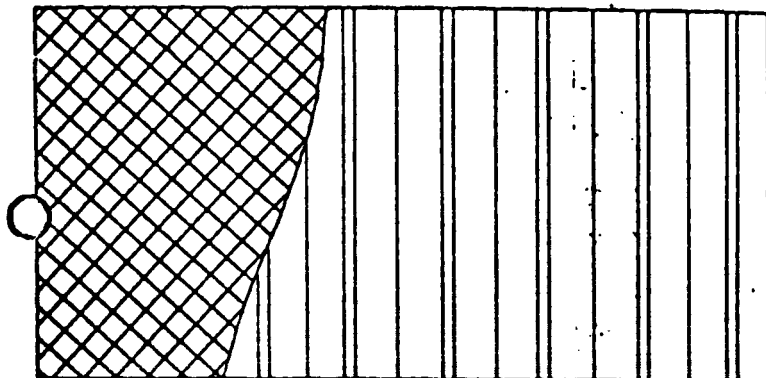
# EFFECT OF IMPURITIES



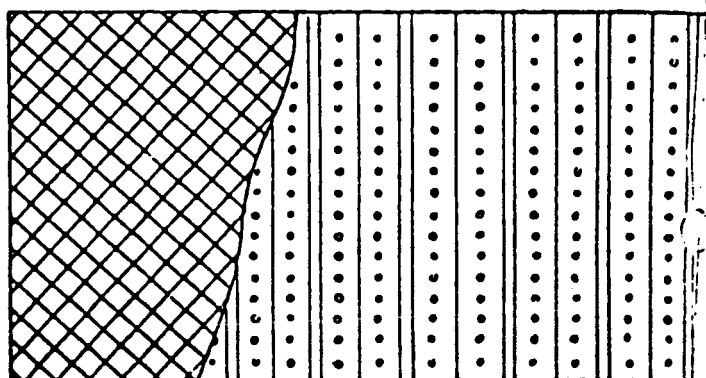
**High Sodium Carbonate Concentration,  
Normal A and B Concentration**  
Remedy: Calcium nitrate plus activated carbon treatment.



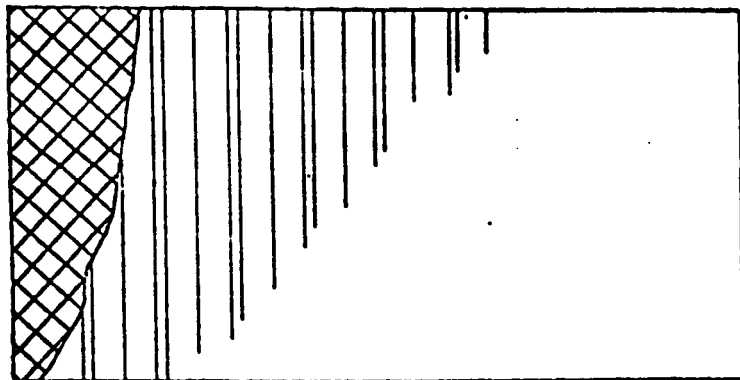
**Inorganic Impurities, Normal A and B Concentration**  
Remedy: Low current density electrolysis.



**Light Suspended Particles, Normal A and B Concentration**  
Remedy: Filtration through Filterbestos.



**Heavy Solid Particles, Normal A and B Concentration**  
Remedy: Simple filtration.



**Effect of Potassium Nitrate on Mixed Sodium and Potassium Baths,  
Normal A and B Concentration**  
Remedy: Usually not noticeable during normal plating. Simple filtration.

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**APPENDIX II**  
**SOLAR CELL INTERCONNECTIONS**  
**PROCESS SPECIFICATION**

APPENDIX II  
SOLAR CELL INTERCONNECTIONS  
PROCESS SPECIFICATION

1. INTRODUCTION

1.1 SCOPE

This document describes the processes and techniques which Electro-Optical Systems, Inc. (EOS) uses to interconnect wraparound solar cells by silver electroforming.

1.2 REFERENCE DOCUMENTS

1.2.1 EOS Mandrel Drawing 81-12056

1.2.2 M and T Chemicals, Sheet No. P-Ag-SL (Appendix I of this document) Silver Lume Bright Silver Plating Process

2. REQUIREMENTS

2.1 Solar Cells

2.1.1 Solar cells shall be of the wraparound type with a maximum picture frame width of 5 mils.

2.1.2 Each cell must pass a tape test to verify adhesion of the sintered silver-titanium contact to the cell.

2.1.2.1 The tape test shall be performed by pressing Scotch tape until the tape is clear over the N and P contacts and then pulling tape free at a rate of 2 to 5 inches per minute in a controlled manner.

2.1.2.2 The cell shall be determined suitable for electroforming if there is no residual silver on the tape after removal.

## 2.2 PROCESS SOLUTIONS

2.2.1 The electroform bath used shall be M and T Chemicals Bright Silver Plating Process prepared per M and T Chemicals data sheet P-Ag-SL.

2.2.2 Activating solution shall be used per M and T Chemicals data sheet P-Ag-SL.

2.2.3 Silver strike solution shall be used per M and T Chemicals data sheet P-Ag-SL.

## 3. PROCESSING

### 3.1 ACTIVATION AND SILVER STRIKE

3.1.1 Thoroughly clean all single-cell plating fixture pieces with Amway Industroclean and deionized water, and assemble cell into fixture for activation and silver strike. Care should be used in tightening cover screws, as overtightening can damage the electrical contacts in the cover.

3.1.2 Place stainless steel anode in activating solution (paragraph 2.2.2).

3.1.3 Attach positive lead from dc power supply to the stainless steel anode and negative lead to the single-cell plating fixture.



- 3.1.4 Place plating fixture in activation solution, facing stainless steel anode, and apply current for 60 seconds at 4.0 volts.
- 3.1.5 Remove fixture from activation solution and immediately place in silver strike solution (paragraph 2.2.3). Apply a direct current of 30 mA for 30 seconds.
- 3.1.6 Remove from silver strike solution and rinse in deionized water.
- 3.1.7 Remove cell from single-cell mandrel and repeat paragraphs 3.1.1 to 3.1.6 until all cells that are to be interconnected are completed.

### 3.2 ELECTROFORMING

- 3.2.1 Wash four-cell cover and mandrel with nonionic detergent or Amway cleaner, scrubbing with soft short-bristle brush. Rinse in distilled water and dry. Avoid lint from towels, cloth, etc.
- 3.2.2 Clean electrical contact wire in cover of four-cell mandrel to insure contact to solar cell.
- 3.2.3 Inspect cells with eye loop for any evidence of roughness. If roughness is present, it is necessary to remove it so the best possible fit between the mandrel surface and the cell edge can be obtained.
- 3.2.4 Carefully place four activated cells in the plating mandrel and install cover. Care should be taken to minimize gapping. Install mandrel cover.
- 3.2.5 Mask screws and electrical connections, as required.

- 3.2.6 Place flat silver anode in electroforming bath (paragraph 2.2.1) and attach positive lead from dc power supply.
- 3.2.7 Attach negative lead of dc power supply to plating mandrel, and place mandrel in bath.
- 3.2.8 Electroform interconnection for 3 hours at a current density of  $10 \text{ amp/ft}^2$  (21 mA for four-cell mandrel).
- 3.2.9 Remove from electroforming bath; rinse mandrel and anode with deionized water.
- 3.2.10 Carefully disassemble mandrel and remove four-cell module; store in plastic box.
- 3.2.11 Clean plating mandrel and box with Amway cleaner for subsequent use.